

*AN ANIMAL MODEL OF EXCESSIVE EATING:
SCHEDULE-INDUCED HYPERPHAGIA IN
FOOD-SATIATED RATS*

JOSEPHINE F. WILSON AND MICHAEL B. CANTOR

COLUMBIA UNIVERSITY

Nineteen rats were maintained throughout the experiment on ad libitum wet mash and water and were trained to press a lever on fixed-interval or fixed-ratio schedules of reinforcement with electrical brain stimulation. Fourteen rats ate at least 150% more mash during intermittent reinforcement sessions than during baseline, massed reinforcement control, and/or extinction sessions. In a 3-hr session, 11 of those 14 consumed more than 22 g of wet mash (13 g dry weight), the equivalent of nearly half an animal's daily food intake. In subsequent control sessions, the electrodes did not support stimulus-bound eating despite attempts to make stimulation parameters optimal. These results indicate that the eating was schedule induced or adjunctive, and suggest that the procedure may provide an animal model of excessive nonregulatory eating that contributes to obesity in humans.

Key words: adjunctive eating, lever press, rats

Schedule-induced behavior patterns are persistent excessive activities that have been observed as by-products of environmental reinforcement contingencies (Falk, 1971). Falk (1961) provided the first demonstration of schedule-induced behavior; when food-deprived rats' lever pressing was reinforced by delivery of food pellets on a variable-interval schedule, the animals drank excessive amounts of water totaling as much as half their body weights in approximately 3 hr. Subsequent experiments (see reviews by Christian, Schaeffer, & King, 1978; Falk, 1971, 1981; Staddon, 1977) showed that polydipsia is one of a family of adjunctive behavior patterns (Falk, 1971) that includes running, grooming, wood chewing, aggression, alcohol drinking, escape, and air licking. Conspicuously absent from this list is schedule-induced eating. The demonstration of schedule-induced eating in rats is important, because it may serve as an experimental model of the excessive eating and sometimes consequent obesity that plagues humans in Western societies.

Schedule-induced eating has been documented in human subjects. Cantor, Smith, and Bryan (1982) had two groups of subjects track on a pursuit rotor for 10-s periods that alternated with 15-s timeout periods without tracking. Snack food and soft drinks were available to the subjects and their consumption, along with facial grooming and manipulating objects on the table, was scored via closed circuit television. When rotor speed was high rather than low, the frequencies of eating, drinking, and grooming were increased. A second experiment (Cantor, 1981a), using a single-subject design, showed similar results. Schedule-induced eating by humans has also been reported by Fallon, Allen, and Butler (1979) and by Wallace, Singer, Wayner, and Cook (1975).

Attempts to produce adjunctive eating in rats have not been as successful. For example, Taylor and Lester (1969) reinforced the lever pressing of water-deprived rats on schedules of water reinforcement. When food pellets were made available, adjunctive eating was not observed. Bellingham, Wayner, and Barone (1979) used the same procedure but optimized the arrangement of food with respect to the position of the water spout. Although they reported adjunctive eating, their results must be questioned: Animals were maintained at 80% of ad lib body weight by restricting water consumption. It is not clear whether the eating was adjunctive or whether it was regulatory in nature.

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Requests for reprints should be sent to Josephine F. Wilson, Department of Psychology, Wittenberg University, Springfield, Ohio 45501. Michael B. Cantor is president of Michael B. Cantor Associates, Atlanta, Georgia.

Since attempts to induce eating in water-deprived rats are complicated by a caloric debt, an attractive alternative reinforcer is electrical brain stimulation. Deprivation is unnecessary and high rates of responding on intermittent schedules of reinforcement can be maintained (Cantor, 1971, 1979). Cantor and Wilson (1978) reported schedule-induced polydipsia with brain stimulation delivered on fixed-interval and fixed-ratio schedules of reinforcement. Mean intake for all animals was 22.5 mL, or about four times the control level, in 3-hr sessions. Atrons (1973) reported transient schedule-induced eating in the context of a fixed-interval 2-min schedule of reinforcement with brain stimulation.

Because evidence of schedule-induced eating by satiated rats would fill a void in the literature on adjunctive behavior and might provide an animal model of nonregulatory eating in humans, it is important to demonstrate the effect unequivocally. The present experiment reports adjunctive eating of wet mash by rats whose lever pressing was maintained by schedules of brain stimulation reinforcement.

METHOD

Subjects

The subjects were male Sprague-Dawley CD rats obtained from Charles River Laboratories that weighed 325 to 400 g prior to surgery at the start of the experiment. Each animal was housed individually and given free access to food and water throughout the experiment. Initially, 48 rats were implanted with electrodes. All but 19 were eliminated from the experiment due to response rates of less than 2,000 per hour on a continuous reinforcement schedule, death, or loss of the electrode before the full series of manipulations could be completed.

Surgery and Histology

Under Chloropent anesthesia, the rats were implanted unilaterally with bipolar platinum electrodes (Plastic Products, Inc.) that were insulated except at the cross section of the tip. The electrodes were located stereotaxically 2.0 mm lateral to bregma and 8.5 mm ventral to the leveled skull surface. Each electrode was secured to the skull by means of an acrylic plastic platform anchored by three U-shaped

stainless steel hooks placed into the sides of the skull.

After completion of the experiment, rats were sacrificed with an overdose of Chloropent and perfused arterially with formalin. Brains were then frozen, sectioned, and stained with cresyl violet. Slides containing processed brain slices from each animal were examined microscopically to ascertain the locations of the tips of the implanted electrodes.

Apparatus

The experiment was conducted in four chambers, each consisting of an inner compartment made of clear Plexiglas except for one sheet-metal wall (intelligence panel) and a steel grid floor. Each was surrounded by a larger box which was light-proofed and insulated for sound attenuation. A small (75 mm diameter) Plexiglas window in the outer box permitted direct observation of the animals or positioning of a closed circuit television camera. A red 25-W lightbulb mounted on the ceiling of the outer box provided illumination for observation. Each box was equipped with an exhaust fan for ventilation.

In each chamber, the response lever was located 4.5 cm above the grid floor and 2 cm from the right side of the intelligence panel (which was 28 cm in width). Positioned 7 cm from the left side of the intelligence panel and 3 cm above the floor was a 3-cm diameter clear plastic disk through which shone the only light (7 W) in the chamber. A plastic dish measuring 12.5 cm in diameter by 2 cm high was secured in front of the lighted disk so that the salience of the food was maximized. A drinkometer was attached to the food dish to record the number of contacts the animal made with the food.

Boxes 2 and 4 were equipped with a second operandum, an omnidirectional toggle switch that was located in the center of the intelligence panel, 4.5 cm above the floor. Box 2 also contained a 7-W white light situated above the toggle switch and 15 cm from the floor. Testing for self-stimulation was carried out in a fifth box equipped only with a response lever that was located 4.5 cm above the floor and 3 cm to the right of the intelligence panel. All programming apparatus was in an adjacent room.

Brain stimulation was programmed from a 60-Hz sinusoidal constant voltage source for Boxes 1, 2, and 5, and from a constant current

stimulator in Boxes 3 and 4. Although these two distinctly different sources produce different kinds of stimulation, they do not produce different behavior patterns or rates of bar pressing (Wilson, 1982). Brain stimulation was delivered to the rat via a mercury commutator suspended above the experimental chamber. The stimulating waveform was monitored on an oscilloscope.

Procedure

All sessions were 3 hr in duration, and each subject received daily sessions in the same box at the same time. For all sessions, a dish of wet mash (150 g) was available in the chamber. The mash was prepared from powdered Purina Rat Chow and water in a 1.5:1.0 g ratio, powder to water. Before each session, nonabsorbent paper was placed in the bottom of the excretia tray to collect any mash that was spilled through the floor. Floor bars were scraped clean after a session and the paper was weighed to calculate the spillage of mash.

For each session, the following data were recorded: the animal's weight before and after the session, the number of lever presses, the amount of mash consumed, and the amount spilled. In addition, subjects were observed directly or via closed circuit television.

Subjects were exposed to a series of conditions in the following order: baseline, massed continuous reinforcement control, intermittent reinforcement, and extinction. As described below, not all subjects were exposed to every condition. For each subject, a condition was maintained until eating stabilized. Stability was defined as five consecutive sessions in which the standard deviation (*SD*) for five sessions was less than 25% of the five-session mean. Table 1 indicates the conditions to which each subject was exposed and the number of sessions each animal required to meet the stability criterion for each condition.

Following recovery from surgery, each rat was tested for self-stimulation. In this test, animals were trained to press, with the reinforcers being 500-ms trains of constant voltage brain stimulation. The voltage was adjusted until each subject responded at a high steady rate. Those rats that emitted more than 1,000 lever presses in 30 min were included in the experiment and randomly assigned to an experimental chamber.

Table 1

Experimental chamber assignments and number of sessions in: baseline (B), massed reinforcement control (M), intermittent schedule (I), extinction (E), intermittent-repeated (I₂), and extinction-repeated (E₂) conditions.

Rat	Box #	Procedures					
		B	M	I	E	I ₂	E ₂
27	3	5	3	6	10	12	0
32	1	7	0	5	8	0	0
33	3	0	3	15	17	12	5
39	1	12	3	15	8	9	0
47	3	0	0	9	6	0	0
49	2	0	0	12	5	5	7
54	3	0	0	7	10	0	0
55	3	11	3	12	16	0	0
56	1	0	3	13	5	0	0
60	4	0	0	14	5	0	0
63	1	13	3	8	5	0	0
64	3	8	3	5	5	0	0
66a	3	5	3	6	5	0	0
66b	4	0	0	14	11	12	8
69	1	7	3	8	5	5	0
70	4	7	0	12	5	5	5
72	1	7	3	5	7	7	9
73	2	8	0	5	6	7	0
74	1	8	3	7	5	0	0

At least 1 week after self-stimulation testing, baseline eating sessions began for 12 subjects (Table 1). During these sessions, the electrode was connected to the mercury commutator but lever presses did not produce brain stimulation. Because some of the 12 subjects that were exposed to baseline pressed the lever as if in extinction and ate considerable amounts of mash during baseline as well, we reasoned that exposure to the baseline condition might affect eating in the intermittent reinforcement condition. Therefore, the other 7 subjects were not exposed to the baseline condition, but rather went directly to the massed reinforcement control condition or to the intermittent reinforcement condition.

Prior to their exposure to the intermittent reinforcement schedule, 11 randomly selected animals (Table 1) were exposed to a massed reinforcement control condition for 3 consecutive days, in which each of 100 lever presses produced brain stimulation (continuous reinforcement schedule). After the 100th reinforcer, extinction was programmed for the remainder of the 3-hr session. Wet mash was available in the chamber throughout this massed reinforcement control condition.

Following baseline and/or control sessions,

Table 2

Five-day mean mash consumption and response rate (per session) in all conditions.

Rat	Procedures									
	Baseline		Massed rein.		Intermittent ₁		Extinction ₁		Intermittent ₂	
	Food g	Resp #	Food g	SD g	Food g	Resp #	Food g	Resp #	Food g	Resp #
73	14.5	2			30.5	2,493	8.6	15	25.6	2,406
27	14.3	1	15.5	2.8	25.4	1,422	8.4	12	25.8	2,881
32	21.3	41			38.7	4,840	15.2	46		
39	16.8	11	18.8	1.3	44.8	1,712	16.7	18	40.2	1,671
74	14.8	1	8.0	1.0	24.6	2,050	9.8	80		
63	10.2	1	11.8	1.4	16.6	981	6.9	72		
55	17.9	13	22.6	9.4	55.9	3,173	24.5	1		
56			24.6	1.8	54.8	1,440	25.6	33		
54					19.5	1,145	10.8	75		
60					35.5	2,533	20.4	15		
66b					17.7	1,444	11.2	48	26.5	2,382
49					23.0	997	14.1	49	21.5	1,408
72	2.9	0	8.5	2.3	31.0	657	17.7	6	35.0	541
33			7.4	3.9	22.5	2,823	14.5	30	22.5	2,485
64	20.9	12	18.9	3.6	16.4	1,262	12.5	42		
70	26.6	131			15.1	1,679	17.6	42	13.3	3,493
69	18.9	1	21.4	4.8	9.5	1,345	12.8	16	11.6	1,323
66a	15.3	9	8.2	4.1	7.6	1,466	11.8	42		
47					28.6 ^a	2,814	15.9	550		
Mean	16.2	28	15.1	3.3	26.1	1,909	14.5	14	24.7	2,067

^a Food was spilled, not eaten.

lever pressing was reestablished with brain stimulation on a continuous reinforcement schedule. After three such sessions, the pressing of rats assigned to Boxes 1 and 3 was reinforced on intermittent schedules, with single trains of brain stimulation as reinforcers, using a procedure developed by Cantor (1971). That is, reinforcement consisted of the pairing of a 500-ms warning signal and brain stimulation in a Pavlovian delay trial wherein signal and stimulation coterminated. (Total duration of the signal was 1,000 ms or 1.0 s:500 ms occurring before the brain stimulation and 500 ms during the stimulation.) This procedure prevents the rapid extinction of the lever-press response during transition from continuous to intermittent reinforcement (Cantor, 1971, 1979). In Box 1, the signal was a 15-Hz click, and in Box 3 it was a buzzer. Table 1 shows each animal's box assignment and the sequence of procedures under which each was trained.

Rats in Boxes 2 and 4 underwent identical continuous reinforcement training as animals in Boxes 1 and 3. However, instead of signaling brain stimulation to prevent rapid ex-

tingtion of the response (Cantor, 1971), a single train of stimulation was delivered contingent on the first response in the terminal link of a chain schedule (Cantor, 1979) using two operanda. Responding was shaped for the chain schedule as follows: After two sessions of responding under continuous-reinforcement conditions where a lever press always resulted in brain stimulation, discrimination training was begun. Lever presses were reinforced only in the presence of the cue light (Box 2) or the buzzer (Box 4). Once lever pressing was under stimulus control, presentation of the discriminative stimulus was used to shape the pressing of a toggle operandum.

Following the above preliminary procedures, all animals (except Rats 32 and 73) were exposed to a fixed-interval (FI) 120-s schedule for the number of sessions indicated in Table 1 as intermittent and intermittent-repeated schedules. Because Rat 73 had a low lever-pressing rate on FI 120 s and a low mash intake level while on that schedule, its schedule was changed to FI 90 s. For Rat 73, Table 1 indicates the number of sessions required for it to reach the stability criterion on FI 90 s.

Table 2 (Continued)

Procedures		Intermit.	Mean wt.— change	
Extinction ₂				
Food g	Resp #	Extinct. %	Inter- mit. g	Extinct. g
		326.2	+8.6	−4.0
		304.8	+5.5	−0.3
		254.6	+8.2	+4.6
		254.5	+10.1	+2.1
		251.0	+3.0	+0.5
		240.6	+7.1	−1.1
		228.2	+9.1	+1.5
		214.1	+10.6	+2.0
		180.6	+7.7	+3.0
		174.0	+9.1	+0.8
14.5	17	172.0	+8.0	+3.3
12.1	3	169.8	+6.3	−1.5
21.5	1	168.4	+9.4	+1.6
12.5	150	166.7	+9.7	+1.2
		131.2	−2.0	−2.0
15.6	25	85.5	−3.4	−3.6
		82.4	−11.0	−7.2
		64.4	−7.4	−0.6
			−7.8	−0.2
15.2	39	171.0	+4.2	+0.2

Rat 32 was trained on fixed-ratio (FR) 50 instead of FI. Only 1 rat was exposed to a FR schedule because of the time and effort involved in training an animal to respond on a FR 50 schedule with brain stimulation as reinforcement. For Rat 32, Table 1 indicates the number of FR sessions required to attain the stability criterion.

Once eating met the stability requirement during the intermittent schedule condition, an extinction procedure was imposed until eating again met the stability criterion. For animals receiving signaled brain stimulation on the schedule, neither signal nor brain stimulation was presented during extinction. For those animals with the chain schedule, toggle presses in extinction never produced the discriminative stimulus. As in intermittent reinforcement sessions, the electrode was always plugged into the mercury commutator.

Upon completion of these procedures, all animals were tested, using the standard procedure of Valenstein, Cox, and Kakolewski (1968), to assess whether the electrode supported stimulus-bound behavior patterns such as eating, drinking, and gnawing. A plate of

wet mash was placed in the experimental chamber along with Purina Rat Chow pellets, a 1-in. cube of pine wood, and a drinking tube. The stimulator was initially set at 0.5 V for Boxes 1 and 2 (50 μ A for Boxes 3 and 4) and was turned on for 30 s and off for 60 s in 10 alternating periods. Thereafter, the voltage was increased by 0.5 V (50 μ A) for 10 more periods. The stimulation intensity was incremented in this fashion until a maximum of 3 V (300 μ A) was reached or until the stimulation produced seizure. The voltage was then decremented in the same fashion. Each test was repeated three times on consecutive days for each rat. Two observers (usually the first author and a trained research assistant) were present during these tests and recorded any stimulus-bound behavior patterns.

As Table 1 shows, intermittent reinforcement was reinstated for 9 of the animals in a replication of the first part of the experiment; the other 10 animals lost their electrodes before the stability criterion was reached. Five of the 9 animals then completed a second series of extinction sessions.

In this experiment, schedule-induced eating was defined as a 150% elevation in amount eaten during intermittent reinforcement sessions as compared to baseline, massed reinforcer baseline, and/or extinction.

RESULTS

Table 2 shows 5-day mean weights of wet mash consumed, mean number of lever presses, and weight changes of the animals. During intermittent reinforcement sessions, 14 of 19 animals ate at least 150% of their mean baseline, massed reinforcer baseline, and/or extinction consumption levels.

Figure 1 shows wet mash consumption for 4 representative rats that met the 150% criterion. The greatest increase in eating during intermittent sessions was shown by Rat 55. It had a high rate of lever pressing on the FI schedule and gained a mean of 9.1 g of body weight during FI sessions, whereas it gained 1.5 g during extinction. Rat 33 gained 9.7 g in body weight as against 1.2 g in extinction, although this animal had the smallest difference among subjects in the amount consumed during intermittent reinforcement. Rat 72 (Figure 1) was the only subject exposed to all condi-

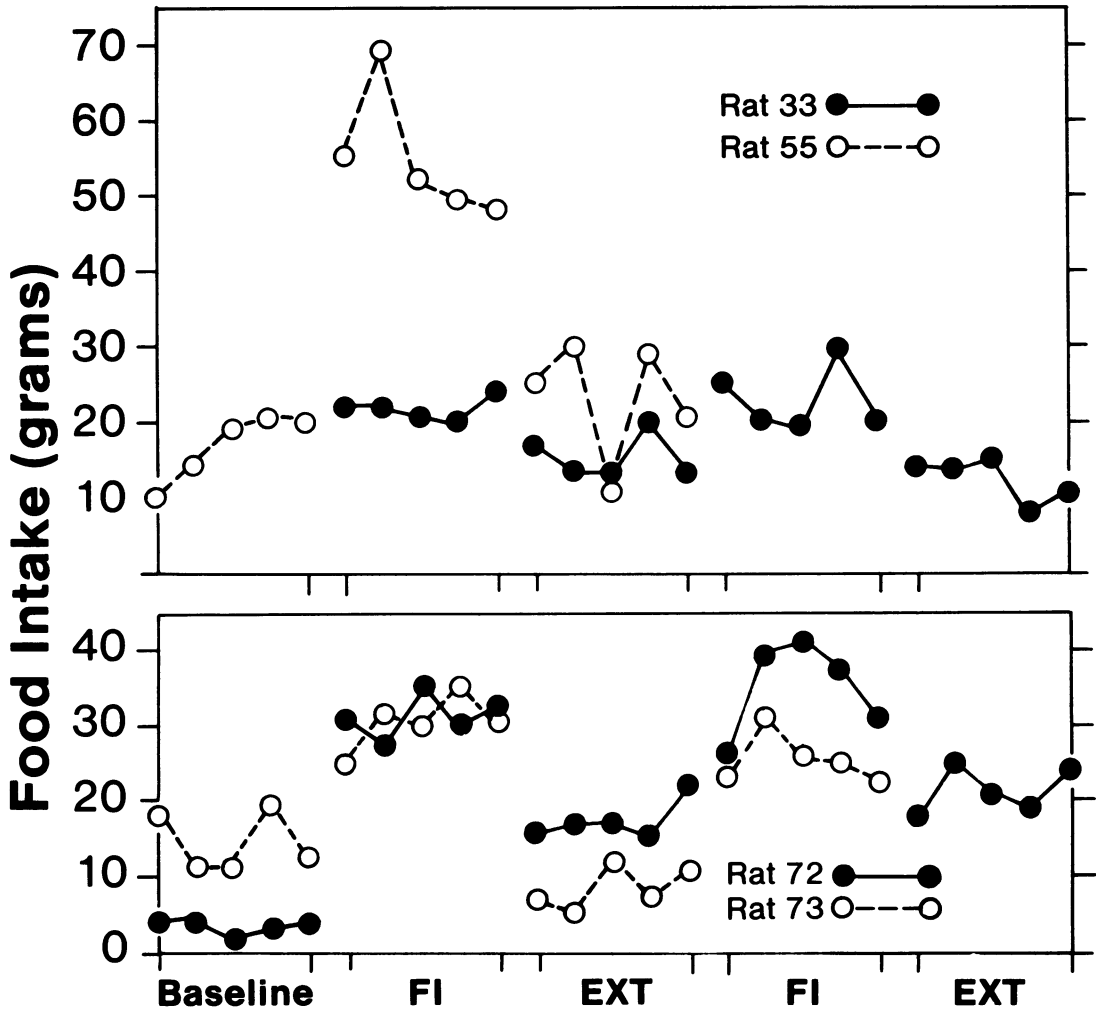


Fig. 1. Representative schedule-induced eating by 4 rats. Graphs show food intake during the five criterion sessions as a function of baseline and intermittent reinforcement schedule (fixed interval and extinction).

tions and 1 of the 12 rats exposed to the initial baseline condition. Its eating during baseline was by far the lowest of the subjects exposed to this condition, and it was also the 1 animal that emitted no lever presses whatsoever during that condition. Considering all animals that were exposed to a baseline procedure, the number of lever presses during baseline was positively correlated with amount eaten during baseline ($r = .67$, $df = 10$, $p < .02$).

Because Rat 73 had an initially low lever-pressing rate on the FI 120-s schedule (796 per session) as well as a low mash intake, its

schedule was changed to FI 90 s. The response rate increased three-fold to 2,496 per session and the amount of mash consumed increased to a high level, as shown in Table 2. Similar to the other representative rats under consideration, this animal gained an average of 8.6 g in body weight during the FI sessions, whereas it lost an average of 4.0 g during extinction.

Direct observation or observation via closed circuit television revealed that most mash consumption occurred shortly after reinforcing brain stimulation was delivered on the FI schedule. Rats receiving brain stimulation on

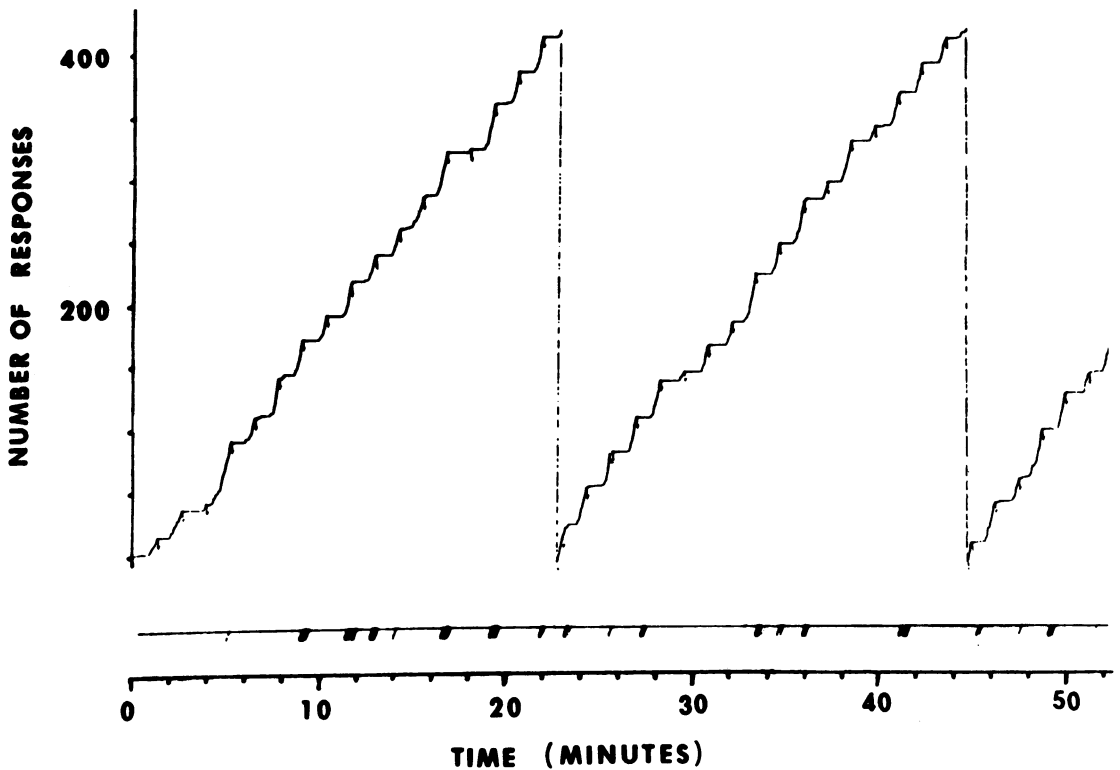


Fig. 2. Cumulative response record for Rat 39 in the 1st hr of a 3-hr session of a fixed-interval schedule. Response rate is represented in the upper channel and laps to the food dish (as detected by a drinkometer circuit) are indicated in the lower channel.

FI schedules tended to linger in the vicinity of the lever for a few seconds following reinforcement before moving to the corner where the dish of mash was secured. Figure 2 shows a cumulative record of FI responding by Rat 39; licks at the food dish are shown in the lower channel. The 1 animal (Rat 32) that responded on an FR schedule had a different pattern. Following brain stimulation reinforcement, this rat typically paused to groom and sniff around the chamber before turning to the dish of mash; after a number of vigorous laps of mash, it returned to the lever and responded until the next reinforcement. Figure 3 shows that eating occurred not immediately after the brain stimulation but rather just before the start of a run of responses.

Rat 47, 1 of the 5 animals that did not eat, appeared to show substantial increases in eating during intermittent reinforcement sessions (180%). However, observation revealed that

much of the food disappearance was due to spillage during interreinforcement intervals rather than eating. This animal lost an average of 7.8 g in body weight during intermittent reinforcement sessions as compared to an average loss of 0.2 g during extinction sessions.

Four of the 19 subjects exhibited neither schedule-induced eating, according to the criteria established above, nor spilling of food. Rats 64 and 66a responded erratically on the FI schedules. Rat 66a rarely left the vicinity of the lever during the interreinforcement interval. Similarly, Rat 69 typically stayed close to the lever during the interreinforcement interval; however, responding on the FI schedule had a regular scalloped pattern. Rat 70 was the only noneater to be exposed to the chain schedule. Toggle pressing continued throughout the interreinforcement interval. It is likely that elevated eating never developed because

poor schedule control resulted in the animal staying consistently close to the toggle and away from the food dish.

That eating increased during the intermittent schedule was shown by both individual and group analysis. Comparing 5-day means of mash consumption during intermittent reinforcement conditions with succeeding extinction conditions (for all but the animal that spilled the food), a *t* test for repeated measures revealed a significant difference ($t = 4.65$, $df = 17$, $p < .001$). The same comparison for the 5 animals (33, 49, 66b, 70, 72) that completed a second replication of the intermittent reinforcement and extinction conditions was also statistically significant ($t = 3.02$, $df = 4$, $p < .05$).

Differences in mash consumption between the massed reinforcement sessions and (a) baseline, (b) intermittent reinforcement, and (c) extinction after intermittent reinforcement were also compared with a *t* test. Intermittent reinforcement produced significantly more eating ($t = 3.0$, $df = 10$, $p < .02$) than the massed reinforcer control. The difference between the amounts eaten in the massed reinforcer control and the extinction sessions, however, were not statistically significant ($t = 0.23$, $df = 10$, $p > .05$); nor was there a statistically significant difference between amounts eaten in baseline and massed reinforcement control sessions ($t = 0.12$, $df = 8$, $p > .05$). Therefore more eating reliably occurred during intermittent reinforcement than during initial baseline, massed reinforcer baseline, and/or extinction.

Changes in body weight (Table 2) confirm the wet-mash consumption data. All subjects satisfying the criterion for schedule-induced eating (i.e., showing a 150% increase over their mean baseline, massed reinforcer baseline, and/or extinction levels) gained more weight during the intermittent reinforcement sessions than during extinction. On the other hand, the 5 animals (Rats 47, 64, 66a, 69, and 70) that either spilled or failed to eat mash all lost weight.

During testing for stimulus-bound behavior patterns, none of the animals ate wet mash, picked up a food pellet, or drank water (interobserver reliability coefficient = 1.00). Six animals showed no response to stimulation except occasional lever pressing; 3 sniffed the floor during stimulation; 5 circled the cage in

a stereotyped fashion; 1 sniffed and circled; 2 groomed. Two animals had seizures at stimulation intensities less than the ultimate value of 3 V or 300 μ A.

Histological data verified that the electrode tips were implanted along the median forebrain bundle at the level of the preoptic area for 16 rats and at the level of the lateral hypothalamus for the rest (Rats 32, 33, 66b).

To determine the amount of wet mash lost due to evaporation during a session, dishes of wet mash were placed in the empty chambers for 3 hr on 7 consecutive days. Evaporative loss averaged 1.4 g (range, 0.8 to 2.5 g) and was judged to be inconsequential compared to the amounts eaten during experimental sessions.

DISCUSSION

Hyperphagia was observed in 14 of 19 (or 74%) food-satiated animals. Of the 14 that ate, 11 consumed an average of more than 22 g of wet mash (13 g dry weight) in 3 hr, which is equivalent to nearly one-half of an adult male rat's typical daily food intake (Wilson, 1982).

That the observed eating was schedule induced is supported by the results of a massed reinforcer control procedure suggested by Roper (1981). Roper argued that a no-reinforcer baseline (or extinction period) changes two factors at the same time: the schedule of reinforcement and the presence of the reinforcer. The massed reinforcer control, presenting reinforcement without the intermittent schedule, is said to separate these two variables. The finding that more eating occurred during the intermittent schedule than during either of these control procedures justifies the conclusion that eating was schedule induced, pending the consideration of two other possibilities.

First, one could argue that the elevated eating during the intermittent schedule was due not to the intermittent schedule of reinforcing brain stimulation but to the brain stimulation itself, that is, that it was stimulus-bound eating (Valenstein et al., 1968). This explanation is convincingly ruled out, since none of the animals exhibited any signs of eating in the tests for stimulus-bound behavior.

Another line of evidence against the stimulus-bound explanation concerns the temporal

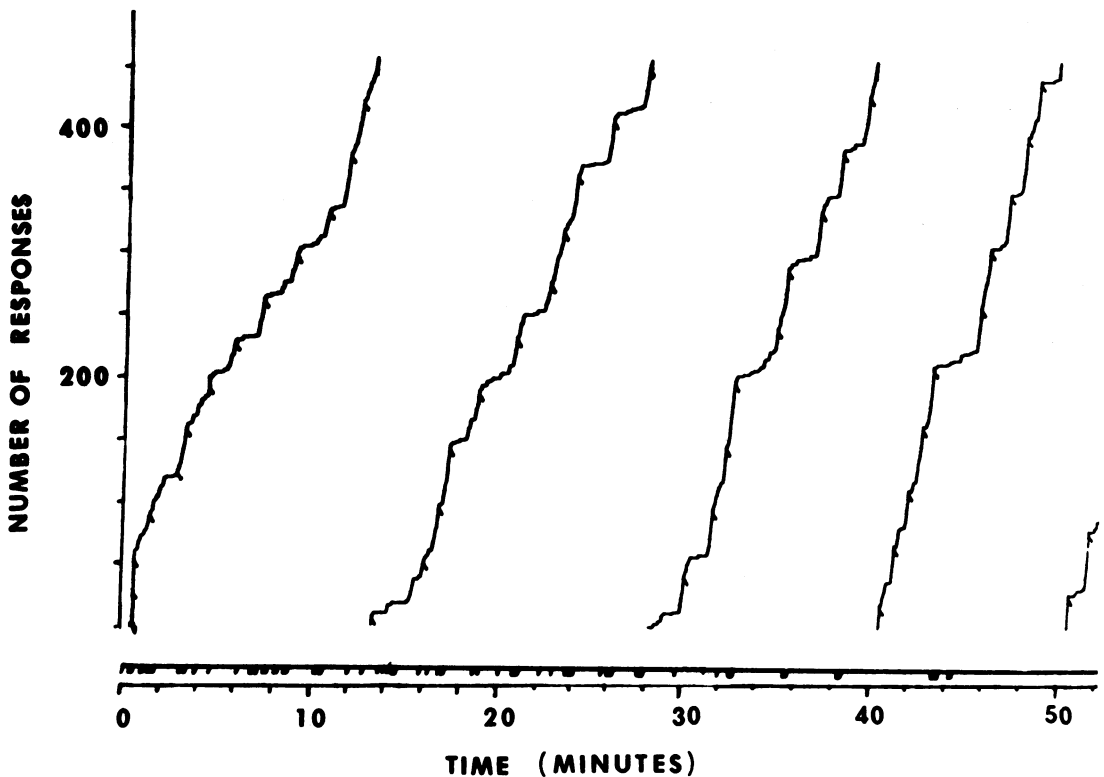


Fig. 3. Cumulative response record for Rat 32 in the 1st hr of a 3-hr session of a fixed-ratio schedule. Response rate is represented in the upper channel and laps to the food dish (as detected by a drinkometer circuit) are indicated in the lower channel.

locus of eating with respect to stimulation. On FI schedules, the eating tended to occur in the period immediately after reinforcement. This supports both the schedule-induction and the stimulus-bound explanations. However, the animal that responded on the FR schedule tended to eat just before the response run, an outcome typical of other adjunctive behavior induced by an FR schedule (Azrin, 1961). This argues for an interpretation of the behavior as adjunctive rather than stimulus bound. The latter would require that eating occur immediately after the reinforcer regardless of the type of schedule on which it is delivered.

Finally, if the eating induced in this experiment were stimulus bound, one would expect to see little eating during baseline and extinction sessions. But substantial eating occurred in those conditions so long as lever pressing was maintained. Considering baseline sessions for 12 animals, lever pressing and eating were

positively correlated. Were the eating a stimulus-bound effect, one would expect a virtual absence of eating in the absence of stimulation and a correlation between responding and eating of zero.

A second alternative explanation for the elevated eating holds that the substantial response rate during the schedule (an average of more than 1,900 lever presses per session as compared to about 65 in extinction) created a caloric debt for which the animal compensated by eating. This argument may be rejected on two grounds. First, there are no available data showing that animals compensate for such short-term caloric deficits (Woods, Decker, & Vasselli, 1974). Second, if animals' eating was in compensation for calories lost, one would expect a net weight gain of zero during intermittent reinforcement sessions. Table 2, however, shows that every animal that ate gained a substantial amount of weight.

In accepting that the hyperphagia observed is schedule induced, it is appropriate to consider why our procedure was successful and others were not. We believe that four factors contributed to our success in obtaining schedule-induced eating.

Individual differences. Simply put, not all animals are disposed to eat as an adjunctive behavior. The 74% that ate in this experiment is comparable with other procedures that induce eating in satiated animals (e.g., 90 dB noise, tail pinch, and thwarted copulation in male rats) (Cantor & Wilson, 1985; Wilson, 1982). Similarly, Cantor et al. (1982) found that 54% of their human subjects adjunctively ate snack food. Why some individuals eat and others don't is a question of considerable interest. Using the tail-pinch procedure, eating occurs in animals with a low pain threshold as shown by the tail-flick response (Cantor, 1981a). Whether pain threshold also predicts schedule-induced eating is an open question.

Type of reinforcement. Some experimenters have attempted to obtain schedule-induced eating with water deliveries as the inducing stimuli (Carlisle, Shanab, & Simpson, 1972; Taylor & Lester, 1969). Only Bellingham et al. (1979) claimed success, but it is unclear whether the small amount of eating that they reported was adjunctive or regulatory in nature, because a water-deprived rat is also a food-deprived rat. Brain stimulation was used as the reinforcer in the present study and this eliminated both the need for food deprivation and the complication of satiation effects.

Salience of the food. We believe that the salience of the adjunctive target in the chamber is also important. The food was placed away from the lever, in an area of the chamber where the animals tended to go during the postreinforcement pause. Furthermore, the only light in the chamber was aimed at the food. Finally, we used palatable wet mash instead of the more usual dry pellets. Atrens (1973), on the other hand, used dry pellets, and neither placed them prominently nor illuminated them. This may have contributed to his finding of inconsistent and transient eating.

Reinforcement schedule. Pilot studies indicated that FI 120-s schedules produced the most consistent adjunctive eating just as they produce among the highest rates of polydipsia with 45-mg food pellets (Falk, 1966). How-

ever, Rat 73 pressed the lever at a higher rate on FI 90 s than on FI 120 s and, correspondingly, showed double the adjunctive eating rate. Choice of schedule parameters with respect to individual animals is therefore important.

The demonstration of induced eating by a schedule of brain stimulation in satiated animals supports Falk's (1971) notion of a generalized family of adjunctive behavior that also includes drinking, running, pica, aggression, and paper shredding. It should be noted that this perspective is directly contrary to Roper's (1981) view that discounts many of the schedule induction phenomena and interprets polydipsia as peculiar to the interaction between food and water ingestion by a hungry animal. In this experiment, eating occurs without water reinforcement by an animal that is not food deprived.

We have argued elsewhere (e.g., Cantor & Wilson, 1985) that oro-facial stimulation (including eating and grooming) occurs when an organism is aroused in one of at least two ways: by an aversive stimulus (e.g., 90 dB noise or tail pinch) or by uncertainty (H_T ; Shannon & Weaver, 1949) about the occurrence of an important event such as reinforcement. The FI 120-s schedule reported here is an example of the latter category; it represents approximately 12 bits of temporal uncertainty (Cantor, 1981b; Cantor & Wilson, 1981) about the occurrence of reinforcement.

Another example of adjunctive behavior induced by uncertainty about an important event involved human subjects engaged in a tracking task (Cantor et al., 1982). During a programmed timeout after tracking on a pursuit rotor, subjects consumed substantial amounts of snack food and soft drink. The higher the rotor speed (and the greater the uncertainty about the location of the target) the greater the amount of adjunctive behavior induced. One particularly interesting finding with humans that is unreported in the animal literature is that subjects who tracked the best (i.e., who had the greatest time on target at a given speed) tended to have eating as their adjunctive behavior whereas those who tracked the worst tended to groom the face.

The present study, then, may provide the framework for an animal model of the environmentally induced eating (Kanarek & Hirsch, 1977) that can contribute to obesity in

people: for example, the moviegoer who munches popcorn when "the plot thickens," the air traffic controller who reaches for the potato chips when there is a lull in the action, or the frustrated writer who visits the cookie jar when the words won't come. However, before this demonstration of schedule-induced eating can be generalized to human snacking, more research is required. For example, it is necessary that the interreinforcement distribution of eating be analyzed more thoroughly for rats exposed to intermittent reinforcing brain stimulation. Also important would be the study of schedule-induced eating in rats exposed to FT schedules of comparable brain stimulation reinforcement.

The phenomenon of schedule-induced eating demonstrated in food-satiated rats in this study will no doubt be better understood as investigation of it continues and as psychologists come to some agreement as to the nature of adjunctive behavior. At present, there are a variety of definitions of and explanations for schedule-induced behaviors (Cantor et al., 1982; Falk, 1971, 1981; Roper, 1981; Staddon, 1977; Wallace & Singer, 1976; Wilson & Cantor, 1986). It is imperative that proposed explanations be tested carefully before any single model is accepted uncritically.

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